

EXHIBIT R

Infant Respiratory Symptoms Associated with Indoor Heating Sources

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This study examined the effects of indoor heating sources on infant respiratory symptoms during the heating season of the first year of life. Mothers delivering babies between 1993 and 1996 at 12 hospitals in Connecticut and Virginia were enrolled. Daily symptom and heating source use information about their infant was obtained every 2 weeks during the first year of life. Heating sources included fireplace, wood stove, kerosene heater, and gas space heater use. Four health outcomes were analyzed by reporting period: days of wheeze, episodes of wheeze, days of cough, and episodes of cough. A large percentage of infants had at least one episode of cough (88%) and wheeze (33%) during the heating season of the first year of life. Wood stove, fireplace, kerosene heater, and gas space heater use was intermittent across the study period. In adjusted Poisson regression models controlling for important confounders, gas space heater use was associated with episodes and days of wheeze. Wood stove use was associated with total days of cough, and kerosene heater use was associated with episodes of cough. Fireplace use was not associated with any of the respiratory symptoms. Use of some heating sources appears related to respiratory symptoms in infants.

Keywords: cough; gas space heaters; infant respiratory symptoms; kerosene heaters; wheeze; wood stoves

Infants spend the majority of their time breathing the indoor air of the home environment and have frequent respiratory symptoms. Although the long-term clinical prognosis of infants who experience symptoms such as wheeze and cough in the first year of life is uncertain (1), infant respiratory symptoms represent a health impact with enormous associated costs, including medical care visits, hospitalizations, and lost productivity for parents. Although infants have some passive immunity against infections, acquired transplacentally and through breast milk, the small caliber of the infant bronchial tree means obstruction to airflow may occur with relatively minor increase in nasal or tracheobronchial secretions or airway surface edema.

Exposure to particulate matter has been linked to increases in hospital admissions for respiratory diseases (2–4), acute respiratory symptoms (5–9), lower respiratory illness (7–12), and decreases in pulmonary function (7, 10, 12–17).

Some studies have focused on populations with existing respiratory disease, such as people with asthma (7, 9–11, 15, 16, 18–20), for whom exposures may exacerbate pre-existing disease. Often, these studies have focused on ambient air exposures. However, assessing exposures in these studies has proven challenging because of the complex nature of the pollutant mix, including both particle and gas-phase components, as well as the variability of concentrations in space and time. The complex nature of the ambient aerosol and strong correlations among ambient concentrations of particulate matter 10 μm or less in diameter (PM_{10}), $\text{PM}_{2.5}$, SO_4^{2-} , and H^+ make it difficult to untangle the role that different physical and chemical aerosol attributes may play in the observed effects. These studies have typically not controlled for the wide range of personal and household characteristics that may be potential confounders for outdoor exposures.

Studying the indoor environment provides an opportunity to clarify some of these effects in infants. Heating sources such as gas, kerosene, wood, and tobacco products are important producers of particulate matter in the home. The nature of the chemical composition of particles varies by source of combustion. Environmental exposure chamber and field studies have identified unvented kerosene heaters as an important indoor source of $\text{PM}_{2.5}$, SO_4^{2-} , H^+ , SO_2 , and NO_2 (21, 22). Unvented or poorly vented gas heaters produce high levels of NO_2 , which is released directly into the home. Wood stoves and fireplaces, even when vented to the outside, may emit high concentrations of pollutants into the indoor air, including respirable particles (23), carbon monoxide, and NO_2 (24), especially during the winter when the home tends to be tightly closed. Studies of the health effects of these indoor heating sources have been inconsistent. Differences between findings could be due to small sample sizes, failure to adequately control for potential confounders, or differences in definitions of outcomes and levels of exposures. Further, the intermittent use of these heating devices in the home has been overlooked. None of the prior studies have accounted for intermittent use patterns of these sources over the course of the heating season.

This study was specifically designed to examine in detail the effects of secondary home heating devices on respiratory symptoms. We test the hypothesis that use of unvented kerosene heaters, gas space heaters, fireplaces, or wood stoves in the home increases the rate of upper and lower respiratory symptom episodes and days during the heating season of the first year of life.

METHODS

Study Population

The study population was recruited by means of a screening questionnaire administered to mothers delivering babies at seven hospitals in Connecticut and five in southwest Virginia between 1993 and 1996. The study was reviewed and approved by the Yale Human Investigations

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Committee as well as the institutional review boards of each of the participating hospitals. Of the 21,448 women screened for the study, 12,848 were eligible after exclusion for smoking in the household, infant death or adoption, maternal age < 19 years, non-English-speaking mother, prior participation, plans to move out of study area, having a multiple gestation, or having no address or phone number. A total of 1,540 women were invited to participate on the basis of their reported exposures, including 352 kerosene heater users, 441 gas stove users, 38 users of both, and 709 control subjects (*see* online data supplement for more detailed information). Approximately 20% ($n = 295$) of these women no longer met study eligibility at the time of the home interview (usually because the mother became a smoker or moved in with a smoker). Of the remaining 1,225 eligible women, a total of 918 (74.9%) enrolled, 299 (24.4%) refused, and 28 (2%) were not enrolled for other reasons. The current analysis is limited to the 890 infants for whom symptom information was available during the winter heating season (October 15–April 15, 1994–1997).

At enrollment, a standardized questionnaire was administered by a trained research assistant during a home interview when the infant was between 3 and 5 months of age. At the home interview, a research assistant described the study in detail to the respondent (infant's mother) and obtained informed consent. The home interview took about 50 minutes to administer and gathered detailed information about the health history of the infant (e.g., birth weight, respiratory illness), infant care (e.g., breastfeeding, daycare), household demographic data (e.g., maternal age, race, marital status, education, number of children in household, income), health status of mother (e.g., self-reported history of allergies or physician-diagnosed asthma), smoking history of mother, medication use of infant and mother, dwelling characteristics (e.g., type and age of residence, number of rooms, heating system), and use of secondary heating sources (i.e., fireplaces, wood stoves, gas space heaters, and kerosene heaters).

Respiratory Symptom Episodes and Symptom Days

After completing the initial questionnaire, the respondent was provided with a calendar to record the infant's daily respiratory symptoms and a brief definition of each symptom. The symptoms of interest were wheeze and cough. The mother was telephoned at approximately bi-weekly intervals (median, 16 days; interquartile range [IQR], 13–19 days) for 1 year by a research assistant and asked to report the presence or absence, and date, of each symptom.

Exposure Assessment

At the home interview, detailed information about the home, including use of secondary heating sources, was obtained from the mother. Accompanying each "biweekly" telephone symptom questionnaire was an exposure assessment that obtained detailed information about frequency of use of each secondary heating source over that monitoring period. Hours of use was multiplied by the number of heating devices used to calculate average source use hours per day during the monitoring period separately for each source (e.g., two devices used for 12 hours/day = 24 hours/day of source exposure).

Data Analysis

Because of intermittent use patterns of home heating sources, analyzing the data by monitoring period preserves exposure and symptom information that would otherwise be lost by averaging over the entire winter season (*see* online data supplement for more detailed information). Because of missing data and variability in length of monitoring periods, the median number of heating source use monitoring periods per infant was 11 (IQR, 11–12), and the total for 890 infants was 9,807. Our analysis is focused on 9,783 (91.6%) of these periods for which infant respiratory symptom information is available.

For each biweekly monitoring period, the number of days the infant experienced the symptom and the number of new episodes of the symptom were summed. An episode is defined as having reported a symptom for one or more days after having had two consecutive symptom-free days. Because our symptom data are in the form of counts (number of days of symptoms and number of episodes), we conducted Poisson regression analysis to examine the relationship between source use and respiratory symptoms, using the GENMOD procedure in SAS (*see* online data supplement for more detailed information). Separate

models were run for the following outcomes: (1) episodes of wheeze, (2) days of wheeze, (3) episodes of cough, and (4) days of cough in each monitoring period. Medians and interquartile ranges (IQR, 25th–75th percentiles) were calculated as a measure of variability in nonnormally distributed data.

Initial unadjusted models examined the association between use of each source separately and the respiratory symptom outcomes. Final Poisson regression models were chosen on the basis of a backward elimination strategy for each outcome. All source use variables—kerosene heater, gas space heater, fireplace, and wood stove use—were retained in final models as continuous variables. Other variables were retained in the model if they were independent risk factors ($p < 0.10$) or if their removal resulted in an increase or decrease in the parameter estimates of the exposure variables of 10% or more.

RESULTS

Mothers enrolled in this study tended to be college-educated, white women (Table 1). Overall, 44% had allergies, but 9% had a history of physician-diagnosed asthma. The majority of families owned their homes and lived in one- to three-family dwellings. Nearly two-thirds of the study homes did not have a gas source. Most infants lived in families with one or two children. Approximately the same numbers of male and female infants were enrolled, some one-third was breastfed for more than 5 months, and a similar percentage was not breastfed at all. One-third of infants did not attend daycare, whereas one-quarter attended daycare an average of 4 hours/day or more. Only 6% of the infants were classified as being low birth weight (less than 2,500 g) based on mother report.

Wood source users (i.e., fireplace and wood stove) tended to be white, more highly educated, own their own homes, live in one- to three-family dwellings without a gas source, and breastfeed their infants (Table 1). The only factors related to gas space heater use were the presence of a gas source and being a low birth weight infant. Kerosene heater users tended to be less educated and own their own homes, but did not have a gas source. Twenty-five percent of participants used fireplaces at least once during the study period, 17% used wood stoves, 3% used gas space heaters, and 18% used kerosene heaters.

Use of secondary heating sources was intermittent during the study period (data not shown). Of 219 fireplace users, the median percentage of monitoring periods in which they used the fireplace was 25%. Wood stove users tended to be more consistent, with use reported in 60% of their winter monitoring periods, followed by kerosene heater users, with reported use in 36% of their monitorings. There were only 25 gas space heater users and they were used in about 18% of the monitoring periods.

The majority of the children had at least 1 day of cough during the winter heating season of the first year of their lives, and nearly one-third had at least 1 day of wheeze. However, most infants did not cough or wheeze during every monitoring period; while 88% ($n = 784$) of infants coughed at least once during the winter, these infants coughed in only about 27% of their monitoring periods. Similarly, 33% of the infants had at least 1 day of wheeze during the winter, but had only wheeze during 10% of their monitoring periods.

The 890 infants contributed a total of 9,783 infant-reporting periods with symptom information available; 2,678 of the infant-monitoring periods had at least 1 day of cough and 503 had at least 1 day of wheeze. Among the infant-monitoring periods with at least 1 day of the symptom, the median days per 14 days of follow-up was 4.4 for cough (IQR, 2.3–7.8) and 3.7 for wheeze (IQR, 1.9–6.0), whereas the median number of episodes per 14 days at risk was 1.2 for cough (IQR, 0.8–2.0) and 1.1 for wheeze (IQR, 0.8–1.7).

Table 2 displays unadjusted associations between use of heat-

TABLE 1. SOURCE USE BY SELECTED CHARACTERISTICS OF STUDY POPULATION, CONNECTICUT AND VIRGINIA, 1994–1996

	n	Fireplace*		Gas Space Heater*		Kerosene Heater*		Wood Stove*	
		% Used	p Value [†]	% Used	p Value [†]	% Used	p Value [†]	% Used	p Value [†]
Overall	890	24.60		2.80		18.10		17.40	
Mother's education									
High school or less	303	12.21	0.001	3.30	0.570	24.75	0.001	16.83	0.480
Some college	261	21.07		1.92		18.39		15.71	
College graduate or higher	325	39.08		3.08		11.69		19.38	
Race									
White or Asian	696	28.74	0.001	2.87	0.830	17.67	0.520	18.68	0.060
Black or Hispanic	193	9.84		2.59		19.69		12.95	
Mother has allergies									
No	497	24.14	0.720	3.22	0.400	18.91	0.470	18.51	0.330
Yes	393	25.19		2.29		17.05		16.03	
Mother has asthma									
No	810	24.94	0.460	2.72	0.590	18.15	0.890	17.28	0.740
Yes	80	21.25		3.75		17.50		18.75	
Family owns home?									
No	311	9.97	0.001	2.57	0.750	13.83	0.010	11.58	0.001
Yes	578	32.53		2.94		20.42		20.59	
Dwelling type									
One- to three-family	708	28.53	0.001	3.11	0.290	18.22	0.840	20.76	0.001
Multifamily/other	182	9.34		1.65		17.58		4.40	
Presence of gas source in home									
No	584	26.54	0.070	1.54	0.002	23.46	0.001	20.03	0.005
Yes	305	20.98		5.25		7.87		12.46	
Other children in household									
None	368	24.46	0.960	2.72	0.740	17.93	0.060	17.39	0.310
One child	334	25.15		3.29		15.27		15.57	
Two or more children	187	24.06		2.14		23.53		20.86	
Season of birth									
Winter	210	25.24	0.750	2.38	0.940	12.38	0.040	20.95	0.180
Spring	271	25.46		2.58		17.71		16.61	
Summer	223	25.56		3.14		19.73		18.83	
Fall	186	21.51		3.23		23.12		12.90	
Infant Sex									
Girl	423	22.46	0.150	3.55	0.210	17.02	0.420	19.62	0.100
Boy	466	26.61		2.15		19.10		15.45	
Months breastfed									
0 mo	300	15.33	0.001	3.33	0.800	21.67	0.110	12.00	0.009
> 0 to ≤ 5 mo	280	28.57		2.50		15.00		19.64	
> 5 mo	309	30.10		2.59		17.48		20.71	
Avg h/d infant in daycare									
None	330	23.33	0.540	3.03	0.220	17.58	0.950	13.03	0.020
< 4/d	325	24.00		3.69		18.46		19.08	
≥ 4/d	235	27.23		1.28		18.30		21.28	
Low-birth-weight infant									
No	837	25.09	0.180	2.51	0.030	18.52	0.190	16.97	0.160
Yes	53	16.98		7.55		11.32		24.53	

* Percent reporting use of source on at least one biweekly monitoring interview during the heating season.

[†] p Value for chi-square; p < 0.05 shown in **boldface**.

ing sources, confounding variables, and respiratory symptoms. Wood stove use is the only source associated with any respiratory outcome in the unadjusted analyses. For every 8-hour per day increase in wood stove use, there was an 8% increase in the rate of cough days (e.g., 1% increase for every additional hour of use per day). Families in multifamily dwellings are also at increased risk of respiratory symptoms. Maternal asthma and allergies, as expected, are significantly associated with wheeze and cough days and episodes in the infants. Lower maternal education increases rates of wheeze and cough episodes, and wheeze days, but higher education increases rates of cough days. Boys have increased rates of all outcomes.

Results from the adjusted Poisson models are shown in Table 3. Several of the source use variables are significant when controlling for important confounders. Gas space heater use, despite the small number of users, is associated with episodes and days of wheeze. Rates of wheeze episodes and days increase

about 25% for every 8-hour per day increase in gas space heater use (e.g., 3% increase for every additional hour of use per day). An 8-hour per day increase in wood stove use increases rates of cough days by 10% (e.g., 1.2% increase for every additional hour of use per day), whereas kerosene heater use increases rates of cough episodes 7% for every 8-hour per day increase in use (e.g., about 1% for every additional hour of use per day)

DISCUSSION

This study provides further evidence that use of secondary heating sources contributes to respiratory symptoms in infants. Use of wood stoves, gas space heaters, and kerosene heaters is associated with wheeze and cough in this cohort. This study is one of few prospective studies designed specifically to examine the relationships between sources of indoor air particulate matter and respiratory symptoms in infants, a potentially sensitive sub-

TABLE 2. UNADJUSTED ASSOCIATIONS BETWEEN SOURCE USE AND RESPIRATORY SYMPTOMS IN INFANTS

	Wheeze				Cough			
	Episodes		Total Days		Episodes		Total Days	
	RR	95% CI	RR	95% CI	RR	95% CI	RR	95% CI
Average per day FP use*	0.35	0.08–1.47	0.19	0.03–1.24	0.30	0.06–1.45	1.03	0.79–1.35
Average per day WS use*	1.07	0.91–1.26	1.04	0.83–1.30	1.06	0.91–1.25	1.08	1.00–1.16
Average per day GH use*	1.20	0.94–1.52	1.16	0.93–1.45	1.26	0.96–1.63	0.93	0.75–1.14
Average per day KH use*	0.85	0.60–1.22	0.89	0.66–1.22	0.85	0.60–1.21	0.96	0.87–1.05
Dwelling type								
One- to three-family	ref		ref		ref		ref	
Four-family or larger	1.38	1.06–1.81	1.60	1.11–2.29	1.38	1.06–1.79	0.98	0.85–1.13
Mother has allergies	1.38	1.07–1.77	1.30	0.93–1.82	1.40	1.09–1.79	1.25	1.10–1.41
Mother has asthma	1.72	1.10–2.69	<i>1.72</i>	<i>0.99–3.00</i>	1.74	1.12–2.71	1.25	1.03–1.51
Average daycare per day*	1.13	0.80–1.60	1.11	0.72–1.73	<i>1.15</i>	<i>1.00–1.34</i>	1.34	1.13–1.59
Mother's education								
High school or less	1.37	1.01–1.86	1.78	1.19–2.68	<i>1.35</i>	<i>0.99–1.83</i>	0.84	0.72–0.98
Some college	1.19	0.86–1.64	1.53	1.03–2.29	1.22	0.89–1.68	0.95	0.82–1.10
College graduate or higher	ref		ref		ref		ref	
Season of birth								
Winter	ref		ref		ref		ref	
Spring	0.93	0.66–1.30	0.95	0.60–1.52	0.93	0.66–1.31	1.13	0.96–1.34
Summer	1.44	1.02–2.04	1.56	0.96–2.55	<i>1.38</i>	<i>0.98–1.94</i>	1.10	0.91–1.32
Fall	1.05	0.72–1.52	1.25	0.73–2.13	1.06	0.74–1.53	1.11	0.93–1.33
Gas source in home	0.80	0.62–1.03	0.74	0.52–1.04	0.81	0.63–1.05	0.93	0.81–1.06
No. of other children in household								
None	0.79	0.55–1.12	0.78	0.49–1.26	0.73	0.51–1.03	0.93	0.79–1.10
One	0.87	0.62–1.20	0.84	0.56–1.27	0.83	0.60–1.15	1.02	0.87–1.20
Two or more	ref		ref		ref		ref	
Breastfeeding months								
None	1.10	0.82–1.47	1.31	0.90–1.91	1.09	0.81–1.46	0.96	0.83–1.11
< 5 mo	1.20	0.87–1.65	1.44	0.95–2.18	1.21	0.88–1.64	1.18	1.02–1.37
> 5 mo	ref		ref		ref		ref	
Infant sex								
Girl	ref		ref		ref		ref	
Boy	1.40	1.09–1.81	1.47	1.05–2.07	1.38	1.07–1.77	1.25	1.10–1.42

Definition of abbreviations: CI = confidence interval; FP = fireplace; GH = gas space heater; KH = kerosene heater; ref = referent; RR = relative risk; WS = wood stove.

Significant ($p < 0.05$) RRs shown in **boldface**; $p < 0.10$ shown in *italics*.

* RRs and 95% CIs based on an 8-hour/day increase in source use and daycare attendance.

group of the population. Major study strengths include extensive demographic and household characteristic information, prospective information about respiratory symptoms in the infant, frequent and regular ascertainment of source use information, and the large sample of infants. By limiting the population to non-smoking households, we eliminated the effect of smoking, which has been found to be strongly associated with respiratory symptoms (25, 26). The study was conducted in the winter months, when subjects are likely to spend more time in close proximity to indoor combustion sources.

An important contribution of this research is the ability of the analysis to account for the intermittent source use patterns. Use of secondary heating appliances varies widely over the heating season, even in the same homes, with periods of nonuse followed by periods of continuous use. This study was able to directly relate symptoms and exposures over shorter periods of time (biweekly reporting periods) rather than averaging use and symptoms over an entire heating season. Averaging source use over longer periods of time or using the presence/absence of a source as a measure of exposure, as prior studies have done, dilutes any effects from such an intermittent exposure.

Respiratory symptoms were common in this large cohort of infants living in nonsmoking homes. Nearly one-half of the study population had at least one episode of wheeze and nearly all had at least one episode of cough during their first winter (October 15

to April 15). Gold and coworkers (12) found a similar prevalence of respiratory symptoms in their higher-risk cohort (i.e., at least one parent had asthma or allergies). The cohort in the current study is more representative of the asthma prevalence in the general population (i.e., only 9% of mothers had diagnosed asthma).

The primary limitations of this study are related to potential selection and recall biases. Women who enrolled in the study tended to be better educated with stable living arrangements compared with those who were ineligible or chose not to participate. Although it is possible that some misclassification may have occurred because of the self-reported nature of some data, frequent follow-up of study participants limited the period of recall and, thus, the potential for misclassification. In addition, questions about infant symptoms were asked before questions about exposure to limit the potential bias from simultaneous reporting of exposure and symptoms.

Gas appliances and gas space heaters are a major source of nitrogen dioxide (NO_2) in residences, exposure to which has been associated with respiratory effects. Several epidemiologic studies have examined whether the presence of a gas appliance is associated with an increase in respiratory symptoms and respiratory infections and with decreases in lung function in adults and children (27–33). Some studies implicate NO_2 in respiratory symptoms or asthma (27, 31, 33); others have failed to find an association (30, 32).

TABLE 3. ADJUSTED POISSON REGRESSION MODELS OF SOURCE USE AND RESPIRATORY SYMPTOMS IN INFANTS

	Wheeze				Cough			
	Episodes		Total Days		Episodes		Total Days	
	RR	95% CI	RR	95% CI	RR	95% CI	RR	95% CI
Average per day FP use*	0.28	0.05–1.42	0.25	0.04–1.43	0.97	0.80–1.17	0.99	0.81–1.21
Average per day WS use*	1.11	0.94–1.30	1.08	0.87–18.39	1.05	0.97–1.14	1.10	1.02–1.19
Average per day GH use*	1.28	0.99–1.67	1.25	1.05–1.50	0.95	0.72–1.26	0.94	0.75–1.18
Average per day KH use*	0.85	0.59–1.21	0.90	0.64–1.25	1.07	1.00–1.15	1.01	0.93–1.10
Dwelling type								
One- to three-family	ref		ref		ref		ref	
Four-family or larger	1.43	1.09–1.86	1.47	1.03–2.09	1.09	0.97–1.22	1.05	0.92–1.20
Mother has allergies	1.25	0.98–1.59	1.33	0.95–1.85	1.20	1.08–1.33	1.22	1.08–1.38
Mother has asthma	1.51	0.98–2.35			1.10	0.93–1.31	1.17	0.96–1.42
Average daycare per day*					1.19	1.03–1.38	1.27	1.07–1.51
Mother's education								
High school or less			1.58	1.07–2.34	0.84	0.73–0.96	0.82	0.69–0.96
Some college			1.32	0.88–1.98	0.90	0.79–1.03	0.91	0.78–1.05
College graduate or higher			ref		ref		ref	
Season of birth								
Winter	ref				ref			
Spring	0.93	0.67–1.30			1.08	0.94–1.25		
Summer	1.48	1.05–2.08			1.19	1.03–1.38		
Fall	1.05	0.72–1.53			1.13	0.98–1.31		
Gas source in home	0.80	0.62–1.03	0.74	0.52–1.06				
No. of other children in household								
None	0.77	0.55–1.07			0.84	0.74–0.97	0.86	0.73–1.01
One	0.91	0.63–1.24			1.01	0.88–1.16	1.01	0.86–1.18
Two or more	ref		ref		ref		ref	
Breastfeeding months								
None	1.07	0.81–1.41	1.06	0.74–1.52	0.96	0.84–1.10	1.04	0.89–1.21
< 5 mo	1.28	0.95–1.72	1.33	0.89–2.00	1.08	0.95–1.23	1.21	1.04–1.40
> 5 mo	ref		ref		ref		ref	
Infant sex								
Girl	ref		ref		ref		ref	
Boy	1.40	1.09–1.80	1.47	1.05–2.06	1.14	1.03–1.26	1.27	1.12–1.44

Definitions of abbreviations: CI = confidence interval; FP = fireplace; GH = gas heater; KH = kerosene heater; ref = referent; RR = relative risk; WS = wood stove.

Significant ($p \leq 0.05$) RRs shown in **boldface**; $p < 0.10$ italicized.

* RRs and 95% CIs based on an 8-hour/day increase in source use and daycare attendance.

Only one other study (34) examined whether unvented gas space heaters specifically were associated with respiratory effects. The cross-sectional study in Australia of 14,124 families with a child between 4 and 5 years of age (34) found an association between use of unvented gas heaters and respiratory symptoms in children. To overcome the bias caused by differences in access to natural gas and wood stove use, the authors restricted the analysis to the 8,154 families living in an area where natural gas was available. However, the study was cross-sectional and did not consider frequency and duration of source use. In addition, the only control for socioeconomic status was an “area measure” based on the proportion of families within a postal code region with low income. In our study, we found that use of gas space heaters was related to both new episodes of wheeze and total wheeze days in infants. We did not ask whether the gas space heaters used in our study were vented or unvented; however, our study confirms these findings in a prospective cohort controlling for several potential individual-level confounders.

Residential concentrations of NO₂ associated with gas cooking ranges and gas space heaters vary as a function of source characteristics, use patterns, and building characteristics (35). Gas ranges tend to be used sporadically and for short periods of time, resulting in an NO₂ concentration gradient with higher levels in the kitchen and lower concentrations throughout other

locations in a residence. Gas space heaters, while having NO₂ emission rates similar to gas stoves, are typically used for longer periods of time and result in less of a spatial concentration gradient in a home. In our study homes, the median use of gas space heaters was 6.6 hours/day (IQR, 2–24 hours/day). Although demonstrating considerable variability, main living area residential levels of NO₂ from gas cooking in winter months are typically in the range of 35 µg/m³, whereas unvented gas heaters are likely to result in residential concentrations four or more times higher and demonstrate less spatial variability within the home (35).

Kerosene heater use increased the rate of new episodes of cough in the study infants. A possible explanation for the association with episodes, but not days, of cough may be that kerosene heater emissions trigger a more immediate, acute reaction rather than a longer-lasting reaction. These findings support the results of a study (36) examining the association between kerosene heater use and allergic symptoms in children and adults in an urban area of Ethiopia. The investigators found an increased likelihood of wheeze, rhinitis, and allergic sensitization among users of kerosene heaters compared with users of biomass fuel only, and proposed that the association was more likely explained by an adverse effect of nonbiomass fuels (kerosene) on allergy rather than on infection. We know of only one other published study (37) of the association between kerosene heater

use and respiratory symptoms, which found that young children exposed to higher levels of NO₂ (30 µg/m³) were at significantly higher risk of lower and upper respiratory symptoms than those who were not exposed. However, the small sample size led to unstable estimates and focused only on NO₂ rather than a broad range of important emissions from the kerosene heaters, including particles and SO₂.

Extensive chamber studies were conducted to evaluate the nature and quantity of particulate emissions from kerosene heaters. These studies indicate that kerosene heaters are an almost exclusive indoor source of sulfate aerosol (SO₄²⁻) and acidic aerosol (H⁺) and an important source of fine particles 2.5 µm or less in diameter (PM_{2.5}) in the indoor environment (22, 38). Numerous studies have found an association between ambient concentrations of PM_{2.5}, SO₄²⁻, and H⁺ and respiratory symptoms, especially in at-risk populations (39). Our finding of an association helps to isolate the effects of SO₄²⁻ and H⁺ by focusing on the indoor environment, where other pollutants and confounders could be more easily controlled. Several studies, particularly in developing countries, have found that use of kerosene heaters or stoves is associated with decreased pulmonary function (40–44).

In our study, median use of kerosene heaters was 2.0 hours/day (IQR, 0.63–6.00 hours/day). Actual concentrations of air contaminants owed to kerosene heater use are related to heater type, use conditions, sulfur content of the fuel, home characteristics, and weather. Nonetheless, active pollutant monitoring in a subsample of 71 homes that participated in this study (38) suggests that the reported median of 2 hours/day of kerosene heater use added about 3.6 µg of PM_{2.5} per m³ and 1.7 µg of SO₄²⁻ per m³ to existing background levels. Residential background levels of PM_{2.5} and SO₄²⁻ measured in a subsample of 144 homes in our study without kerosene heaters during the winter months was 17.4 and 1 µg/m³, respectively, suggesting increases over background of 20 and 170%, respectively.

Emissions of pollutants into residences from both fireplaces and wood stoves are difficult to characterize because of differences in design, use, and type of wood burned. In this cohort, fireplace use was not significantly related to cough or wheeze, which may be due to the short duration of exposure. Fireplaces tended to be used infrequently and for shorter periods of time (median of 0.61 hour of use per day averaged over the reporting periods), and so might offer less opportunity to contribute particulate matter into the indoor air.

Wood stove use was related to days of cough in the study infants. Although it is generally accepted that wood stove emissions can irritate upper airways (45), epidemiologic evidence of an association between wood stove use and respiratory symptoms has been controversial. The association between indoor wood smoke and respiratory symptoms has been examined in more detail, particularly in developing countries, where wood burning for heating and cooking are more common. The effects of biomass burning in open hearths on respiratory symptoms and other outcomes in children and adults have been striking (24, 46–48). In studies of wood-burning stoves in developed countries, results have been more equivocal. Four of six studies involving children in developed countries found that use of wood-burning stoves increased the likelihood of respiratory symptoms or illness (49–52). However, one study (53) found a decreased risk of symptoms among children living in homes in which wood or coal was the primary source of heat compared with those with central heating. Another study (54) found no association between having a woodburning stove as a primary source of heat and respiratory illness in a group of U.S. schoolchildren. Our finding is consistent with those previous studies that found an association between wood stove use and respira-

tory symptoms in developed countries (49–52), but is inconsistent with findings of no association (54) or of a negative association (53). Differences in findings may be due to inadequate control for confounders, cross-sectional study designs, or differences in measures of exposure and outcomes. In addition, none of the prior studies took into account the intermittent nature of exposure to these sources in the way that we were able to do by frequent questioning of mothers about symptoms.

The design of the current study allowed for the most detailed and largest prospective epidemiological evaluation of the association between secondary heating sources—home fireplaces, heating stoves, and kerosene heaters—and respiratory symptoms in infants, a population generally considered at risk. The findings suggest a significant, modest effect of these sources.

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